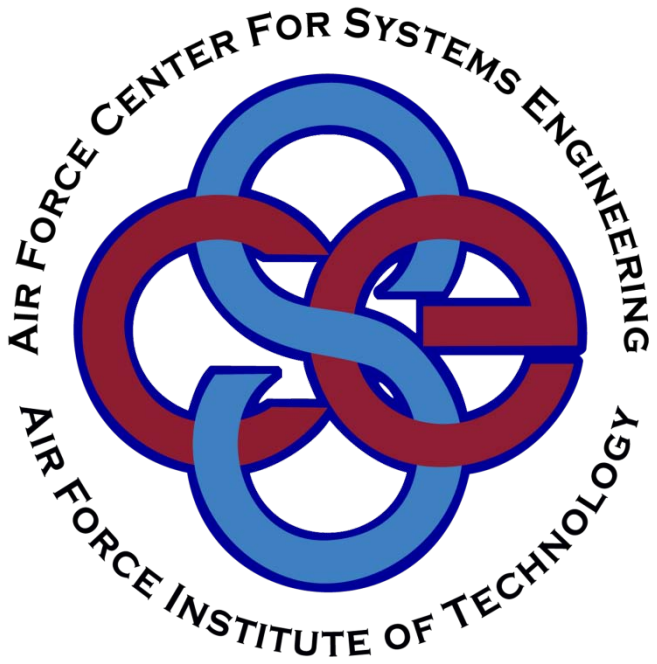
Systems Engineering Research



David Jacques, Ph.D.
Chair, Systems Eng Programs
Department of Systems and Engineering Management

20 Oct 08

Report Documentation Page

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SE "Research"

Statements on SE Research by INCOSE

- Systems engineering is an integrative discipline which, like other engineering specialties, needs vibrant research
- INCOSE advocates the articulation of programs in basic and applied research in Systems Engineering
- INCOSE supports strongly doctoral level research in Systems Engineering

System Science Working Group

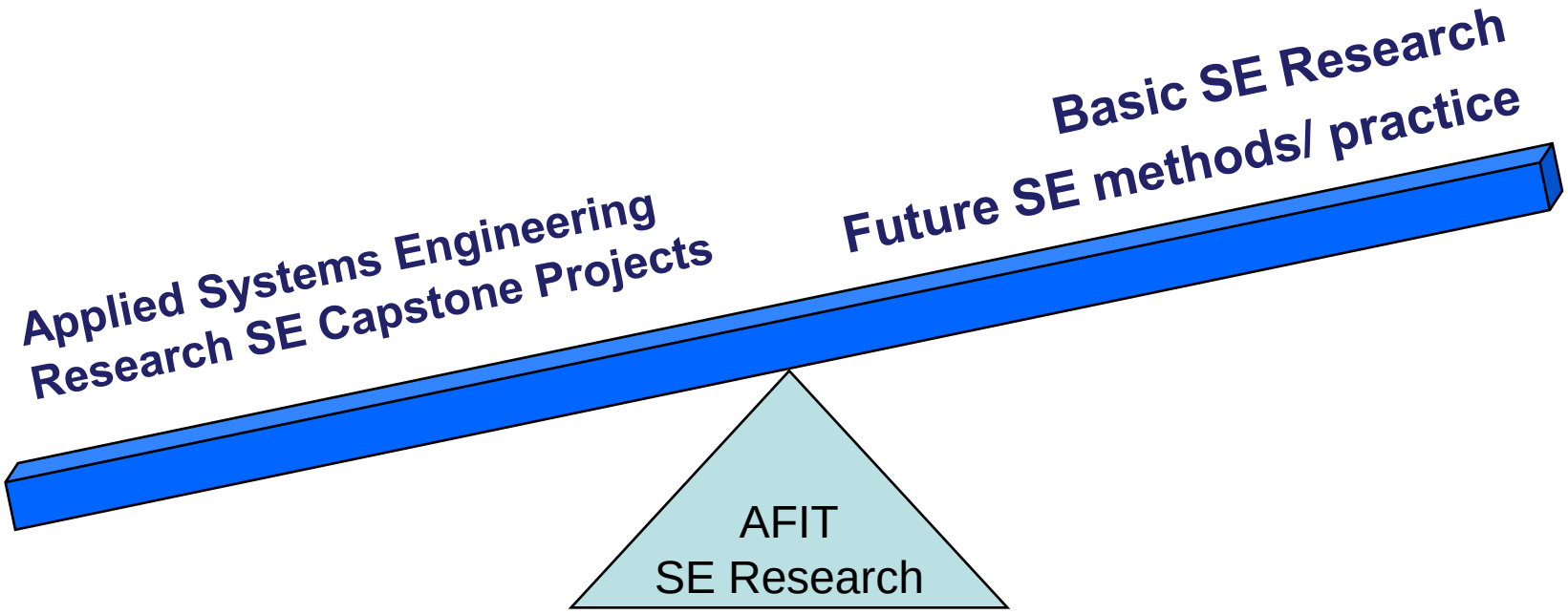
System Science is the enabling theoretical foundations and scientific underpinnings of systems engineering that contribute to better understanding of systems engineering practice, particularly of complex systems and large-scale enterprises

Conference on Systems Engineering Research (CSER)

AFIT SE Research

- **All SE graduate programs require a capstone project**
  - Group projects provide integrated design team experience
    - Thesis for Masters (12 credits, 3 qtrs)
    - Capstone Design Project for IDE (9 credits, 3 qtrs)
    - Capstone for Certificate (4 credits, 1 qtr)
  - Individual Dissertation for Ph.D. students
- **AFIT solicits research grants just like civilian institutions**
  - Resident military student tuition is paid for, but …
  - Civilian faculty are on academic year appointments (10 months), and …
  - AFIT is not budgeted for research related travel, supplies, and equipment
  - We are cheap, but we are not free!
- **Funding for the SE group has been growing**
  - Over $600K in 2008
  - Has allowed us to bring faculty from other programs onto SE projects

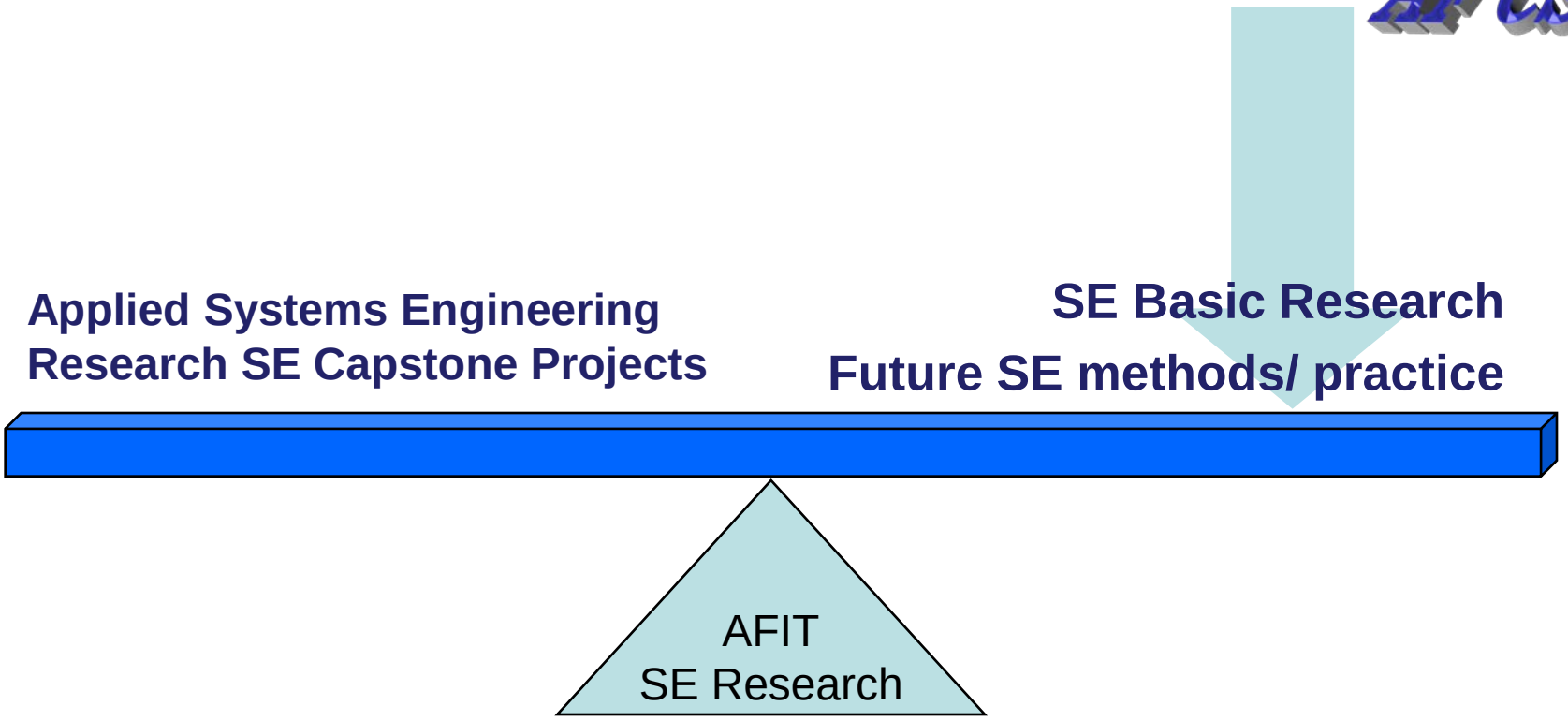
Balance Application of SE Practice with Basic SE Research



Last year, the balance clearly tipped towards the applied research side

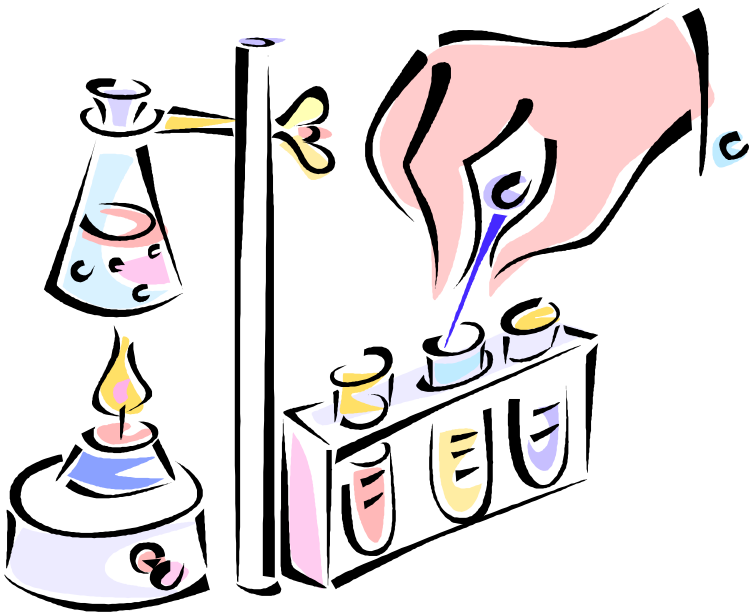
- **Only one PhD student (our first) in dissertation research**
- **Sponsors of MS student research tend to focus more on application**

Balance Application of SE Practice with Basic SE Research



This year, the balance has been tipped towards more basic research

- **More PhD students in dissertation research**
- **Greater effort to "shape" MS topics to address more fundamental questions**



BASIC RESEARCH

Challenge
Who funds Basic SE Research?

- **National Science Foundation**
  - Funds System Science, but typically not Systems Engineering
- **AFOSR**
  - Responsible for oversight and management of the Air Force program in basic research (6.1)
  - Orchestrates the research program with universities, industry, other government organizations, and the AF Research Lab (AFRL) technical directorates
  - AFOSR funding – traditional science areas
    - Aerospace and Materials Sciences
    - Physics and Electronics
    - Mathematics, Information and Life Sciences
- **SE University Affiliated Research Center (UARC)**
  - New initiative, funded by OSD, NSA
  - Award will be announced Oct 08 - Stevens Institute leading a large multi-university team
  - AFIT will participate in the UARC with the Stevens-led team

- We invite the AF CSE advisory council to help identify SE basic research funding sources

AFIT Basic Research Threads

A Sample of SE Basic Research at AFIT

- **SE process improvements**
  - Modeling and evaluation of architectures
  - Modeling cognitive processes within the DoD Architecture Framework
- **System of Systems/ Network Centric Systems Analysis**
  - Graph Theory of Network Centric Operations
  - Interoperability Measurement
- **Integrated Health Monitoring**
  - Reliability models to support life cycle system design
- **Human Systems Integration (HSI) Design**
  - Graph theoretic analysis for HSI evaluation and design
- **Modularity in design vs. performance**

AIR FORCE CENTER FOR SYSTEMS ENGINEERING

Architecting Cognition within the Department of Defense Architecture Framework (DoDAF)

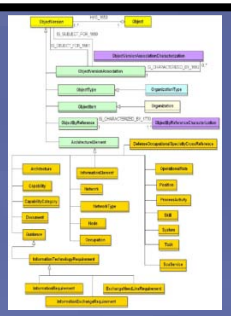
Research Sponsor: AFRL/RH, Wright-Patterson AFB

Maj David O'Malley Major Jonathan Zall

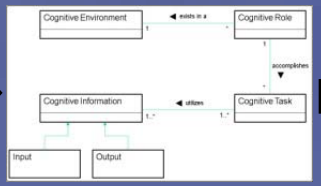
Problem: The design of complex, socio-technical systems requires that critical aspects of the whole integrated system be specifically defined upfront so that the implemented solution addresses human system integration (HSI) facets as well as technical system integration facets. HSI factors and constraints are not incorporated in the US Military acquisitions process until late in the process resulting in unnecessary risk incurred, cost overruns, and mission shortfalls.

Method: Define the cognitive aspect of Human Factors and develop a model of cognitive and pseudo-cognitive (CPC) elements for inclusion in DoDAF via the Core Architecture Data Model (CADM). Demonstrate the efficacy of DoDAF extended with CPC model during the Joint Capabilities Integration Development System (JCIDS) process.

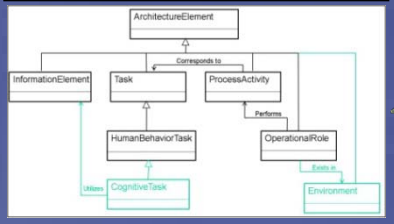
DoDAF version 1.5



Cognitive Elements



CADM with CPC Extension

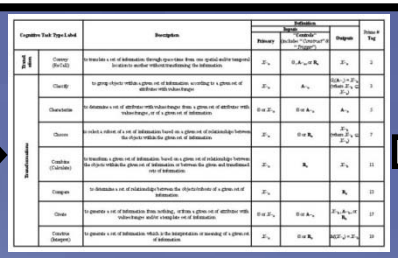


HUMAN

COGNITION

DoDAF version 1.5 Operational View-5

Fundamental Cognitive Tasks



New Operational View incorporating CPC tasks

Results:

- Standardized means for incorporating elements of human cognitions (Environments, Roles, Tasks, Inputs and Outputs)
- Accurate solution trade space constraints with traceable manpower, personnel, and training requirements
- Decreased cost, risk, and mission shortfalls of final solution
- Provide foothold for all other elements of HSI within the JCIDS process

INTEROPERABILITY MEASUREMENT

UNIQUE & SUBSTANTIAL CONTRIBUTION

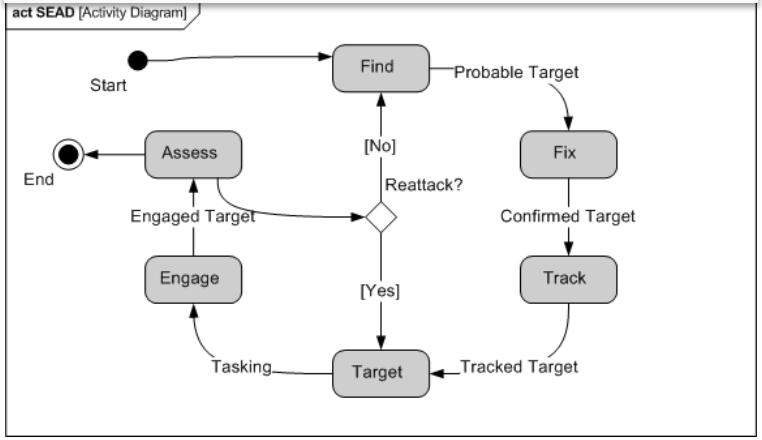
This research presents an inaugural general method of quantitatively measuring the collaborative and confrontational interoperability of a heterogeneous set of systems

The method:

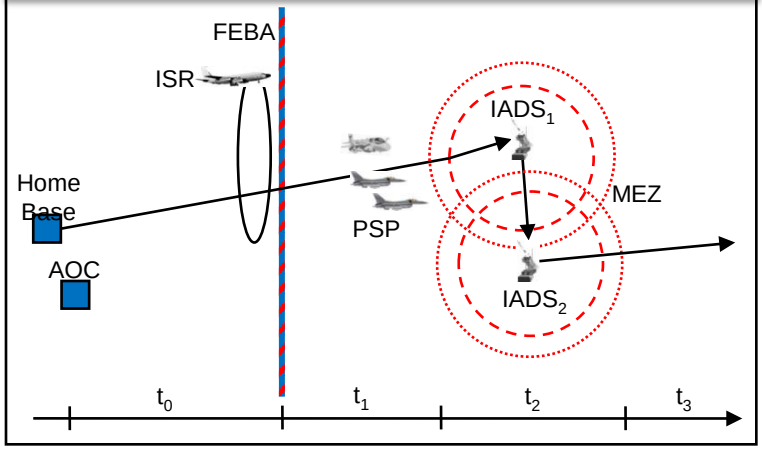
1. Accepts all system types (e.g., coalitions, technology, organizations, cultures, etc.)
2. Accepts all interoperability types (e.g., enterprise, joint, semantic, technical, etc.)
3. Describes interoperability in the context of an operational process
4. Provides for higher precision of measurement
5. Introduces confrontational interoperability and relates it to operational effectiveness
6. Accommodates all types of interoperability characteristics
7. Capitalizes upon existing architecture data

Suppression of Enemy Air Defenses

Operational Process



Operational View



Interoperability Model*

$$S = \{S_B, S_R\} = \{\{HB, ISR, AOC, PSP\}, \{IADS_1, IADS_2\}\}$$

$$X = \begin{Bmatrix} 27 \text{ characters representing} \\ \text{joint operational function hierarchy} \end{Bmatrix}$$

$$C = \{0,1\}$$

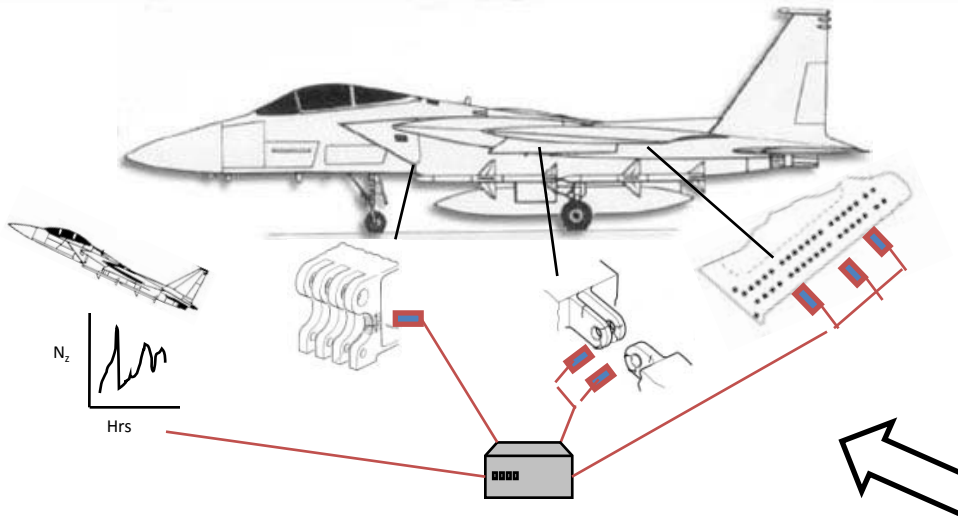
$$O = \{O_B, O_R\} = \begin{Bmatrix} \text{Percent of enemy air defenses destroyed,} \\ \text{Percent of enemy air defenses protected} \end{Bmatrix}$$

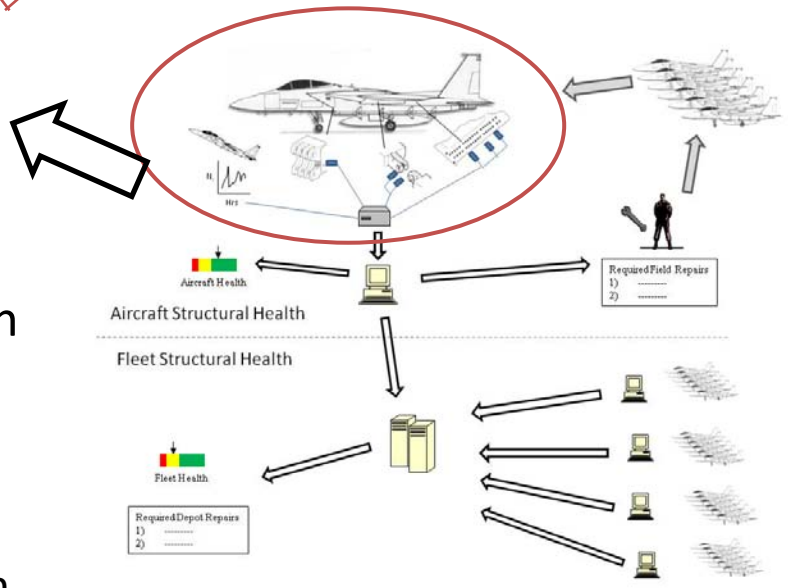
$$I = Sim_{Bin}$$

* System instantiation not pictured due to large size

Interoperability Measurement

$$M = \begin{bmatrix} & HB & ISR & AOC & PSP & IADS_1 & IADS_2 \\ HB & 0 & 1/9 & 1/9 & 1/9 & 2/27 & 2/27 \\ ISR & 1/9 & 0 & 5/27 & 8/27 & 2/9 & 2/9 \\ AOC & 1/9 & 1/9 & 0 & 4/27 & 2/27 & 2/27 \\ PSP & 1/9 & 1/9 & 1/9 & 0 & 7/27 & 7/27 \\ IADS_1 & 2/27 & 5/27 & 5/27 & 10/27 & 0 & 1/3 \\ IADS_2 & 2/27 & 5/27 & 5/27 & 10/27 & 1/3 & 0 \end{bmatrix}$$



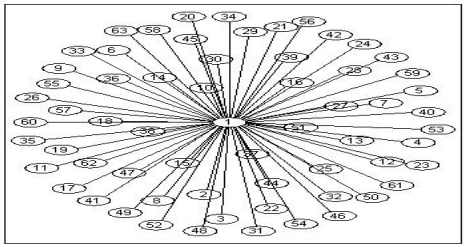


Research Question

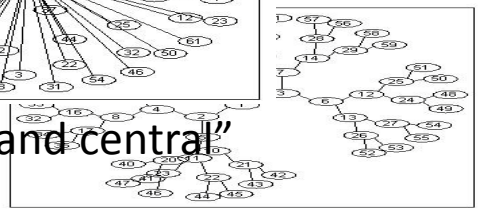
- How can the capability of a Structural Health Monitoring system be estimated over the remaining life of a legacy aircraft?
  - Critical to maintaining a SHM system after installation
  - Provides information for SHM system design trade-offs
  - Provides information for Cost-benefit analysis
    - More SHM maintenance = Less cost savings
  - Method must relate to current practice for practical acceptance

IV. Verification

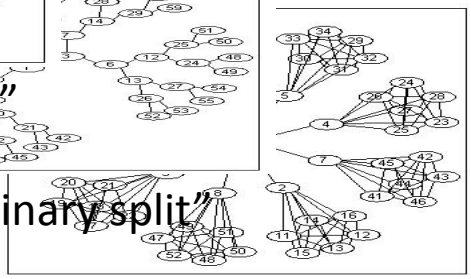
V. Selection



III. Alternative Design

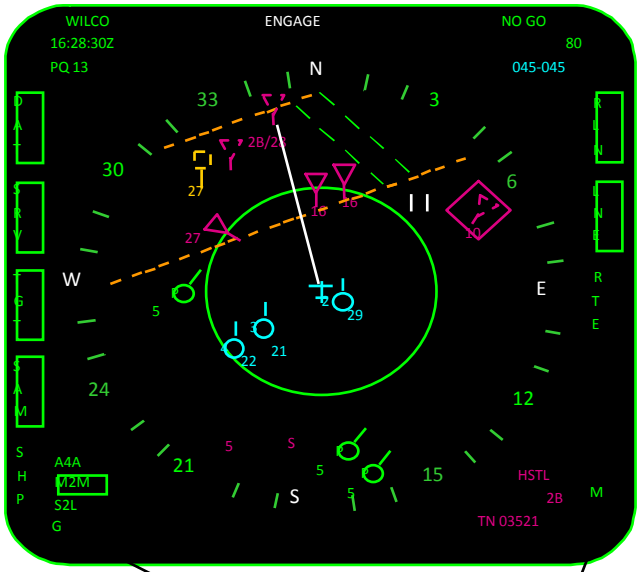


1: “Grand central”



2: “Binary split”

3: “Operational grouping”



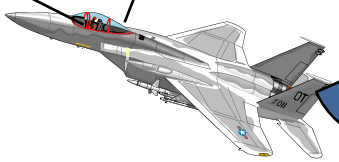
I. Requirements Generation

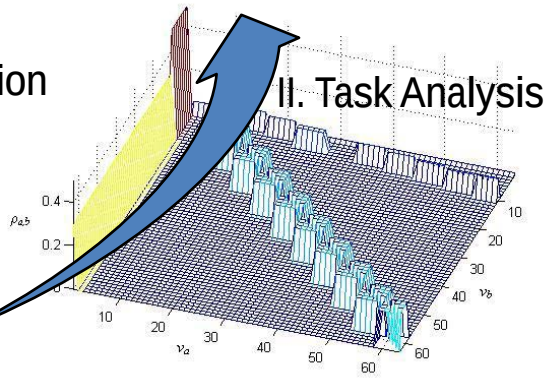
Mission: Multi-role

n=63

t_i=1.0ms

…





II. Task Analysis

13

APPLIED RESEARCH

AFIT Applied Research Threads

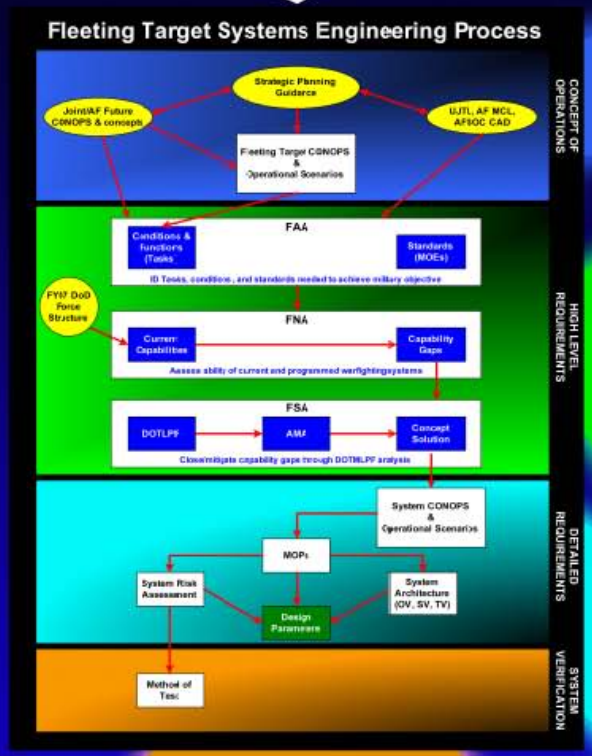
A Sample of Applied SE Research at AFIT

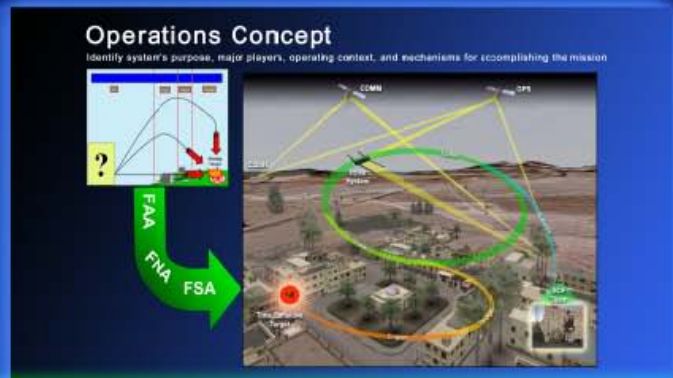
- **Rapid Response to Urgent Warfighter Needs**
- **Interdisciplinary/Interdepartmental Projects**
  - Cooperative small air vehicle surveillance concepts
- **Early SE Application for Technology and Capability Planning**
  - Analysis of functional autonomy
  - Process modeling and risk analysis for decision making
- **Architecture Modeling for Concept Evaluation**
  - Evaluating military worth using architecture based discrete event simulations
- **Spacecraft Dynamics and Control Testbed**

AIR FORCE CENTER FOR SYSTEMS ENGINEERING

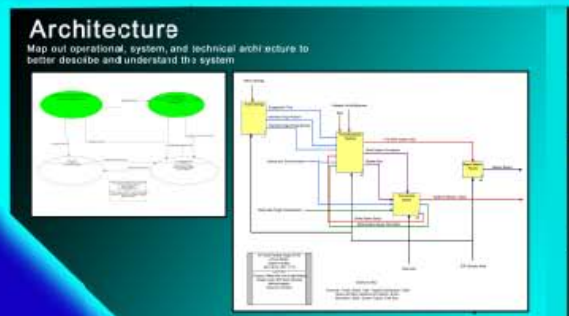
Systems Engineering Analysis For Transition of Fleeting Target Demonstrator

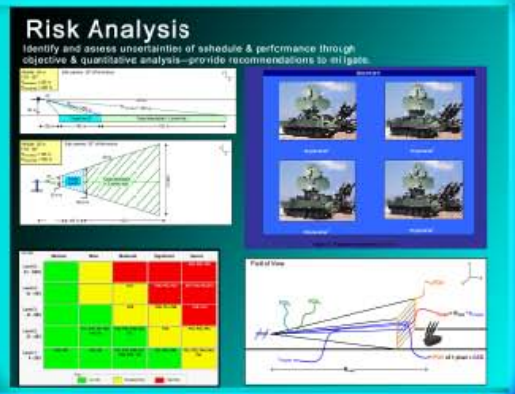
Maj Laird Abbott, Maj Craig Phillips, Mr. Christian Stillings, Capt Garrett Knowlan





JCIDS Analysis





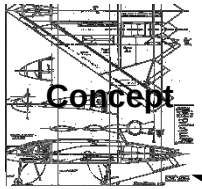
A Focused Systems Engineering Approach to Rapidly Transition Technology to the Warfighter

AIR FORCE CENTER FOR SYSTEMS ENGINEERING

An Analysis of Functional Autonomy

Sponsored by AFRL/RBAA

LCDR Scott Rivera Captain Anil Hariharan Captain Alan Louie



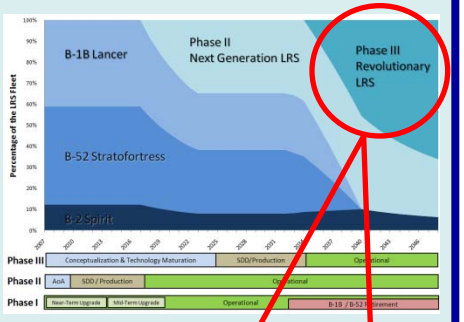
Establish 2035 Vision

Planners
Operators
Doctrine
Guidance

→ Operational Concept →

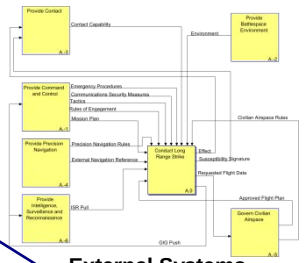
Global Strike
Persistent Attack
Time Sensitive Attack
Nuclear Strike
Show of Force

Problem

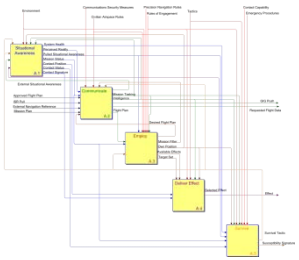


Can the 2035 LRS System be Automated?

Describe System



External Systems Diagram



LRS Activity Diagram

Identify Human Roles

Perception
- Goal Monitor
- Radio Operator
- Sensor Operator

Role

Execution
- Final Safety
- System Director

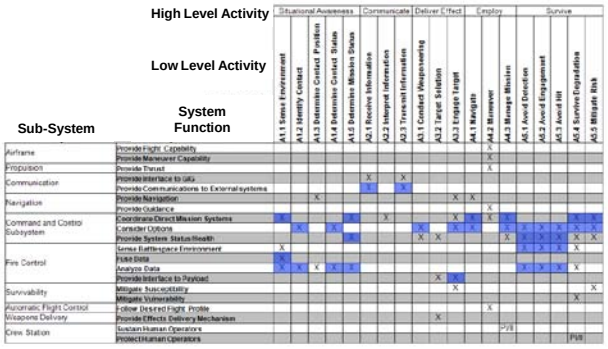
Role

High Level Activity

Low Level Activity

Sub-System

System Function



Planning
- Navigator
- Weaponeer

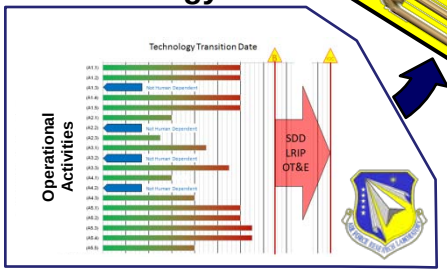
Role

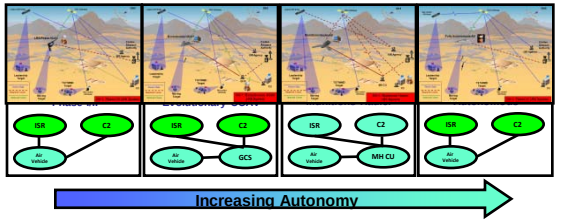
Interpretation
- Data Analyst
- Data Fuser
- Data Sorter
- Decision Maker
- System Health Analyst

Role

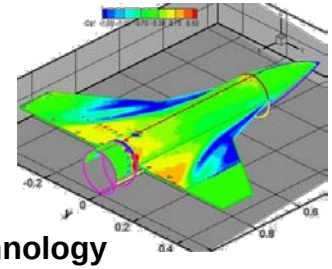
Methodology

Forecast Technology





Illustrative Variants



Technology

Results

- The 2035 LRS system can be Automated
- Concept can be linked to enabling Technologies

AIR FORCE CENTER FOR SYSTEMS ENGINEERING

Creating a Discrete Event Simulation to Determine the Military Worth of Developing an Electronic Warfare Battle Manager Function within an Airborne Electronic Attack System of Systems Architecture

Research Sponsor: Capability Planning Office ASC/XRS, Wright-Patterson AFB, OH
Mrs. Trina Bornejko, Maj Charles Glasscock, Maj Dennis Sprenkle

Results

Measures of Effectiveness	No EWBM	EWBM		
	Baseline	No Decision Authority	Limited Decision Authority	Full Decision Authority
M1 Minutes to reassign AEA Assets				
M2 Percent reduction in of SAM detection rate due to jamming				
M3 Percent of strike aircraft Pd by Pop-up SAMs on route				
M4 Percent of strike aircraft Pd by known SAMs on route				
M5 Percent of strike package attritions due to enemy air defenses				
M6 Percent of strike packages whose mission is degraded by enemy air defenses				

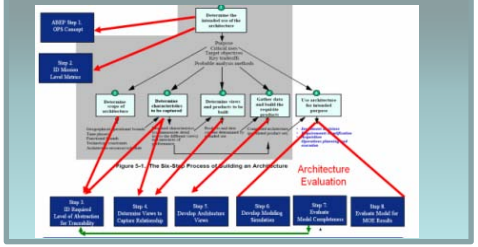
Statistically significant improvement
No statistically significant improvement or degradation
Statistically significant degradation

Problem Statement

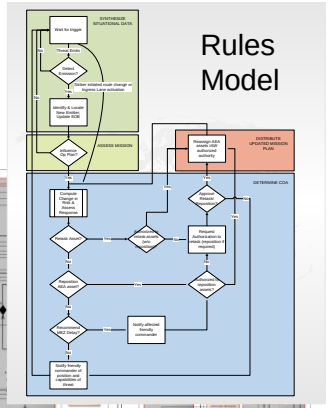
How can the AEA SoS architecture be used to evaluated the military worth of an Electronic Warfare Battle Management (EWBM)?

Operations Concept

Architecture Based Evaluation Process

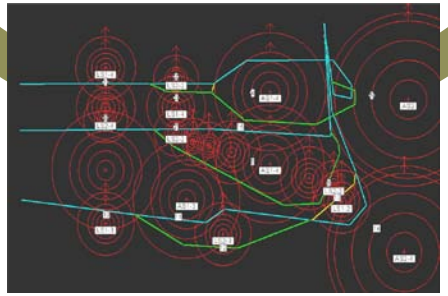


AEA SoS Architecture

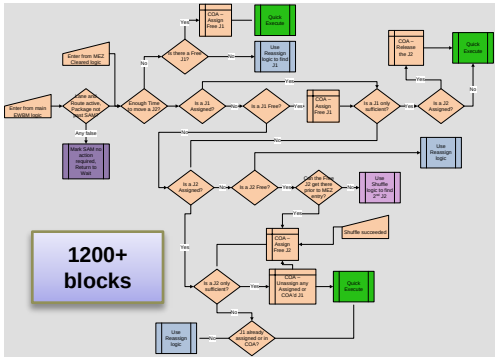


OV-5

Falcon View Mission Plan

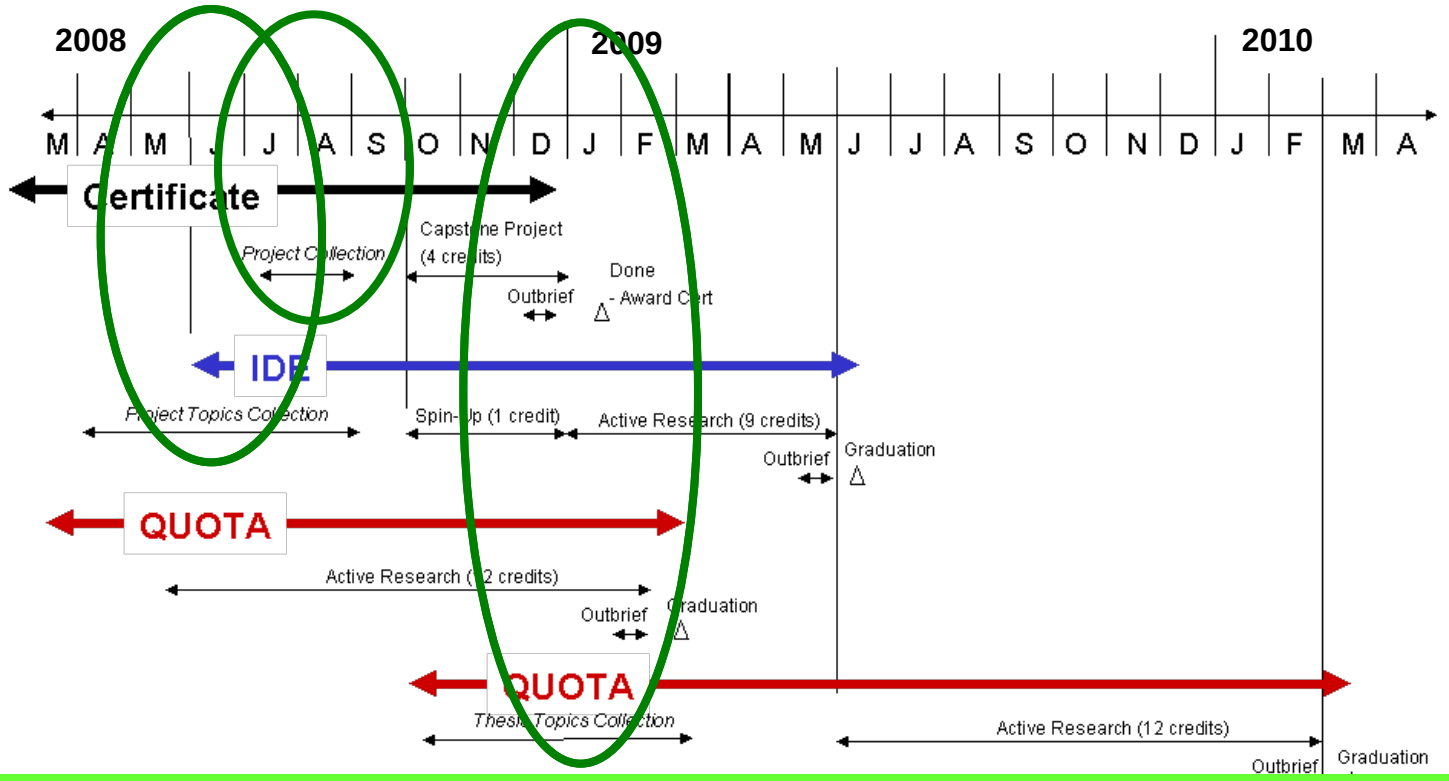


ARENA Simulation



Challenge:
Finding the best projects

- We invite the committee to sponsor relevant projects for our SE students



Target Times for new projects: May-August (Certificate and IDE), Nov-Feb (Quota)

Conclusion

- **AFIT is focusing more effort on Basic SE Research**
  - Interoperability
  - Reliability and Integrated Health Monitoring
  - Design for Human Systems Integration

- **SE Research should include <u>applied</u> research activities in SE process improvement**
  - Early Enterprise and System Architecture and evaluation
  - Executable Architectures
  - Network Centric Operations modeling (graph theory, CPNs)

Contact Us –
We are here to solve complex DoD problems

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  - Industrial & Systems Engineering
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- David Jacques, Ph.D.
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  - Cooperative Control, Optimization, Early SE
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Contact Us –
We are here to solve complex DoD problems

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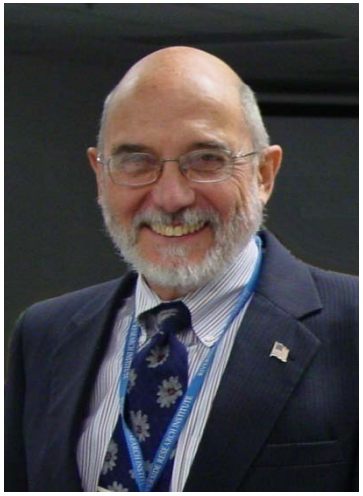

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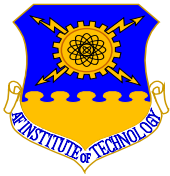

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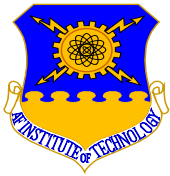
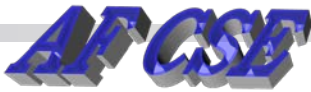
QUESTIONS ?



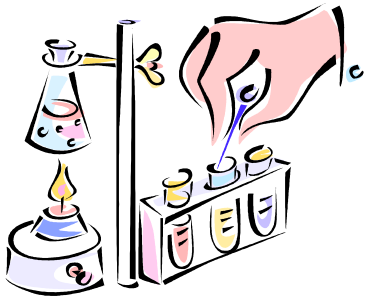


- Backups

Research Definitions

Basic Research Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. It is farsighted high payoff research that provides the basis for technological progress. …

Refs: Office of Management and Budget Circular A-11 on budget regulations, Federal Acquisition Regulations, DOD's *Financial Management Regulation* (DOD 7000.14-R)



Research Definitions

Applied Research Applied research is systematic study to understand the means to meet a recognized and specific need. It is a systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods. It may be oriented, ultimately, toward the design, development, and improvement of prototypes and new processes to meet general mission area requirements. Applied research may translate promising basic research into solutions for broadly defined military needs, short of system development. …

Refs: Office of Management and Budget Circular A-11 on budget regulations, Federal Acquisition Regulations, DOD's *Financial Management Regulation* (DOD 7000.14-R)